SIERRA ENERGY

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SoCalGas
A Sempra Energy utility

PG&E

Feasibility Study:
FastOx® Gasification for Wood Waste to RNG

Study Execution

- Motivation
  - Production of RNG to help green the CA economy (SB 32, AB 3232, SB 100)
  - Assist with waste wood, forest and agricultural biomass residue conversion (decreasing fire risk and lowering overall criteria pollutant emissions)
  - Extend life of existing CoGen facilities, with associated local community economic benefits

- Main Focus
  - Generic California site, 1000 PSIG RNG injection pressure and meeting Rule 21 and Rule 30
  - Engagement with proven RNG Isle manufacturers, optimization of the combined FastOx-RNG plant
  - Evaluate LCOF vs various factors (pressure, LCFS credit, biomass fee/cost etc.)
  - Provide baseline study to progress into further project development

- Main Documents Generated and Final Deliverables
  - Feasibility-level Engineering Documents (for multiple plant configurations): Design Basis, Process Description, BFD, PFD (inc. Utility Summary), Major Equip. List, Site Plot Plan, CAPEX and OPEX
  - Final Report including LCOF Calculations and corresponding Optimal Plant Configuration selection.

FastOx Gasification

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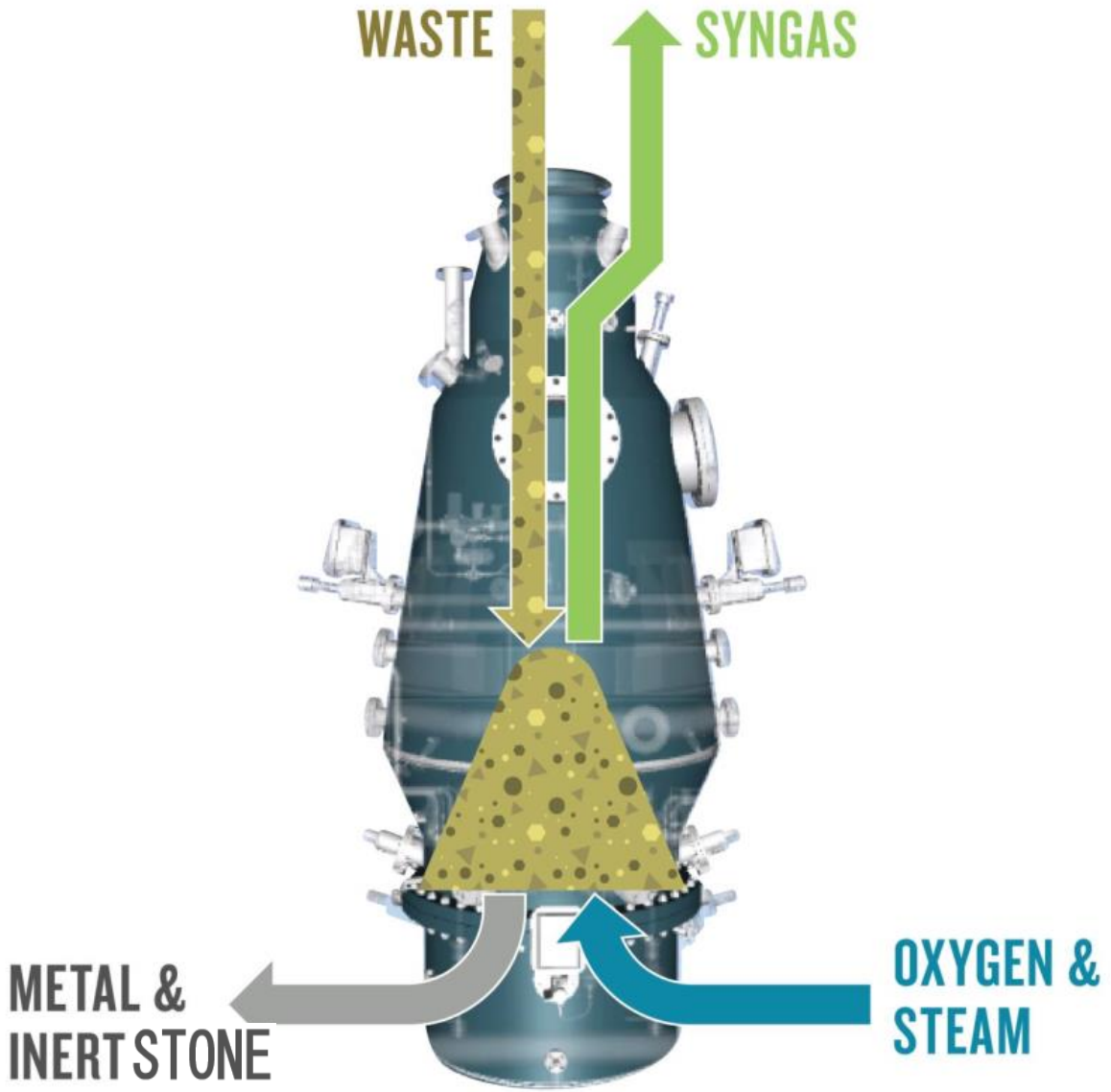
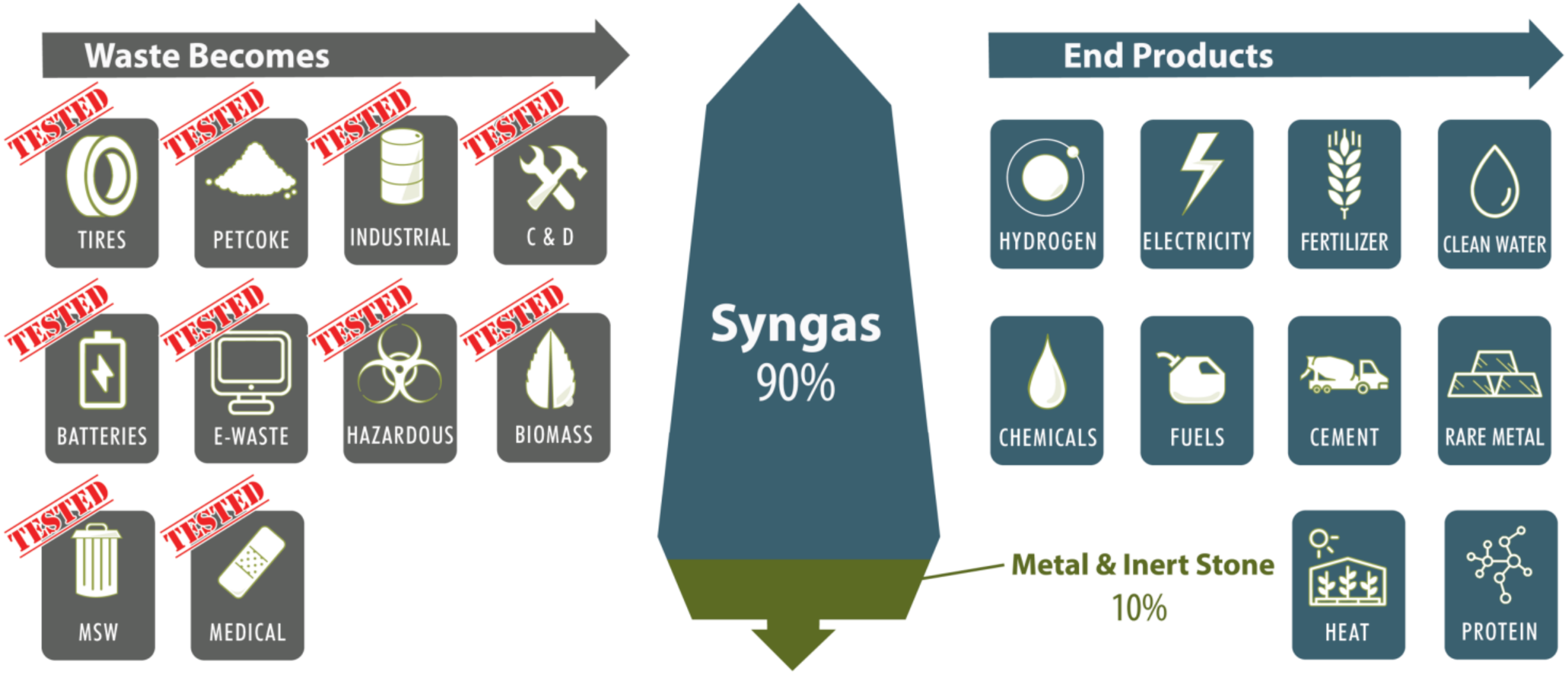


FastOx Gasification



FastOx Gasification

Study Execution – Additional Assumptions

- Major Assumptions
  - Site: Generic CA location
  - Feed Material
    - 40%wt. Forest Thinnings, 40%wt. C&D Wood Waste, 20% Ag. Residues
    - See below compositions. Assuming a conservative ~36%wt. moisture.
  - Utility Costs
    - Local Natural Gas: $3.00/MMBTU

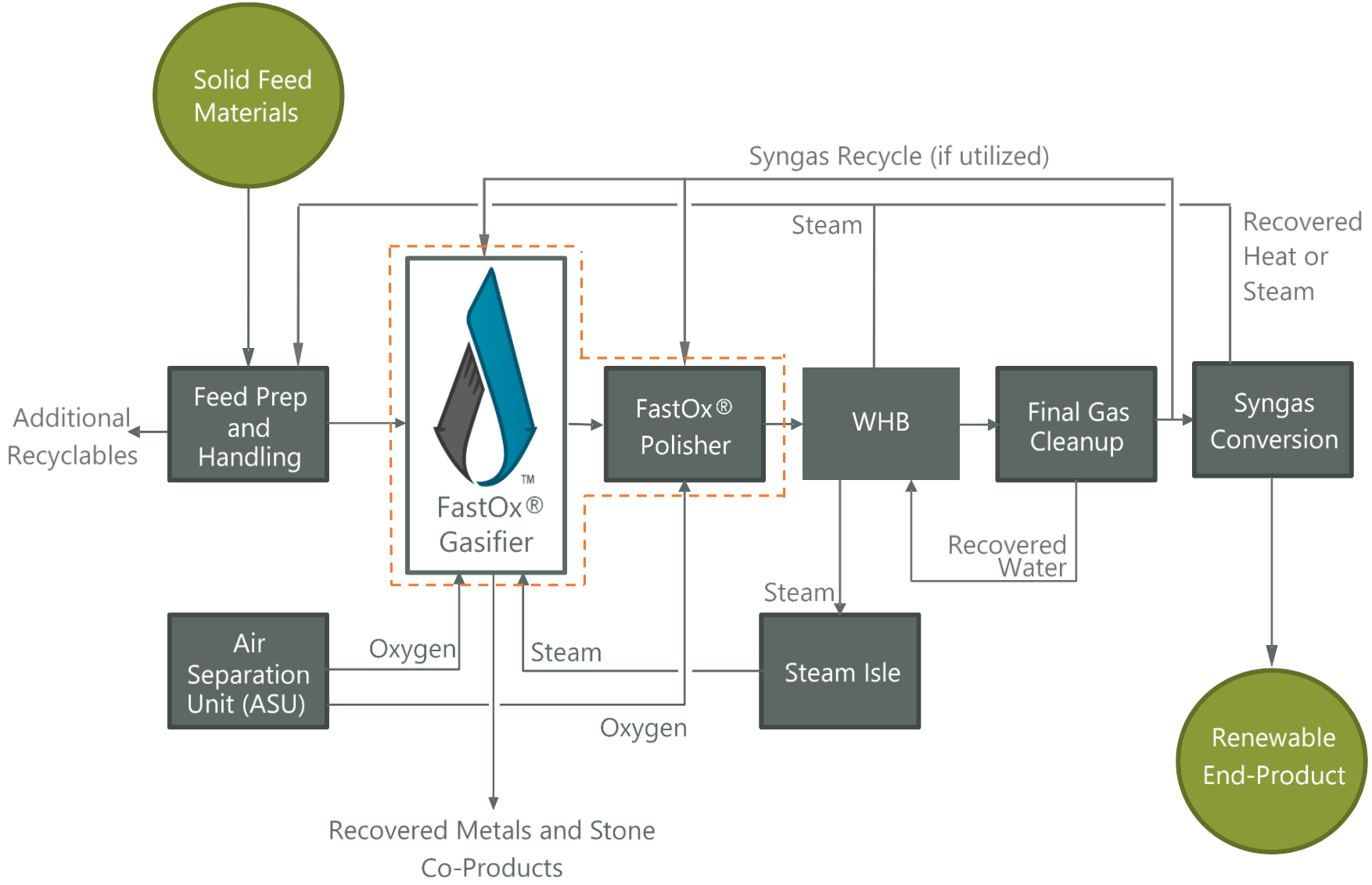
      (2019 Forecasted Avg. Procurement Cost)
    - Local Electricity: $0.120/kWhe

      (2019 Forecasted Wholesale Cost)

Proximate Analysis			
	%wt. (AR)	%wt. (BD)	%wt. (IF)
Moisture	35.9%	0.0%	10.0%
VM	49.2%	76.7%	69.1%
FC	12.8%	20.0%	18.0%
Ash	2.1%	3.3%	2.9%
	100.0%	100.0%	100.0%

Ultimate Analysis		
	%wt. (BD)	%wt (IF)
Moisture	0.00%	10.00%
Ash	3.20%	2.88%
C	49.16%	44.24%
H	5.91%	5.32%
N	0.86%	0.77%
Cl	0.00%	0.00%
S	0.07%	0.06%
O	40.80%	36.72%
	100.0%	100.0%

Study Execution – Basic BFD

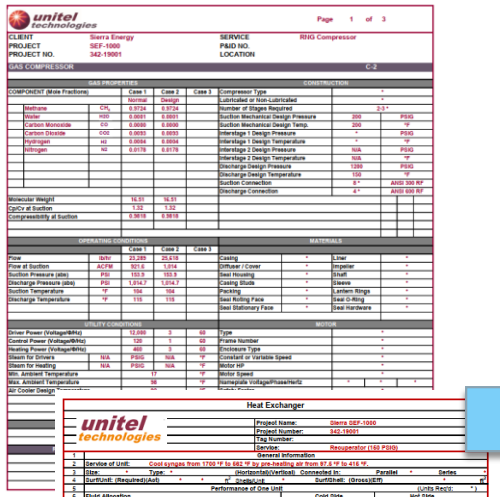


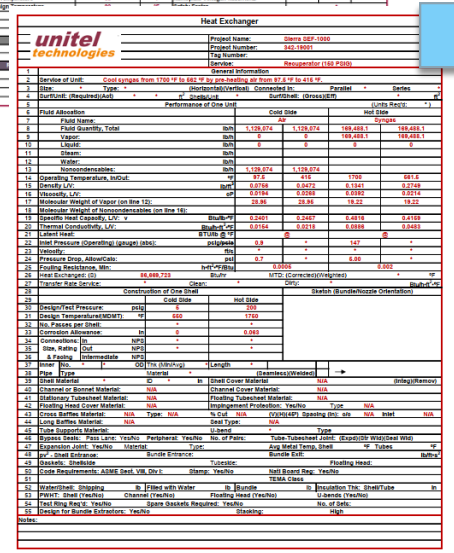
Study Execution – Multiple Vendor Engagement

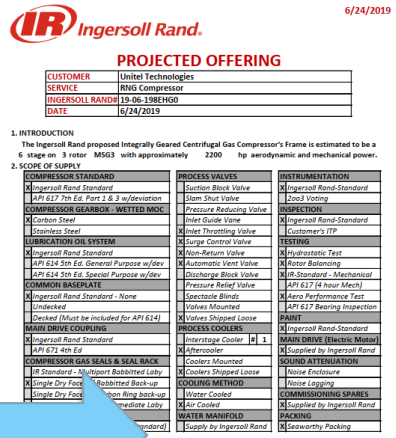
Detailed specification sheets.

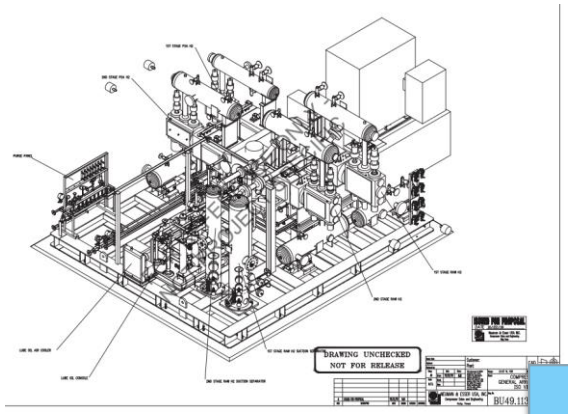
Preliminary Design Packages Received.

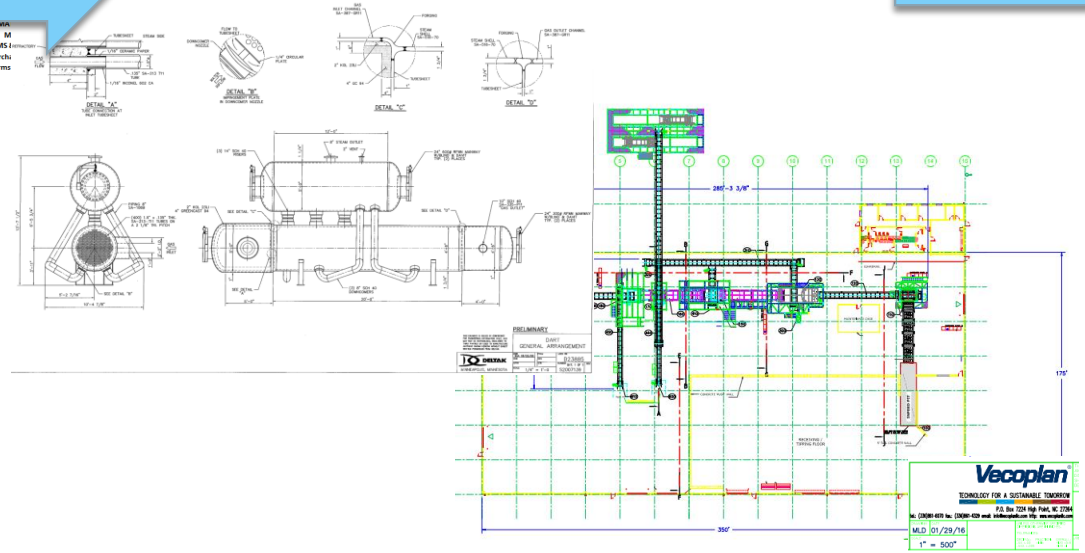
Bid-Tab Analysis and Downselect

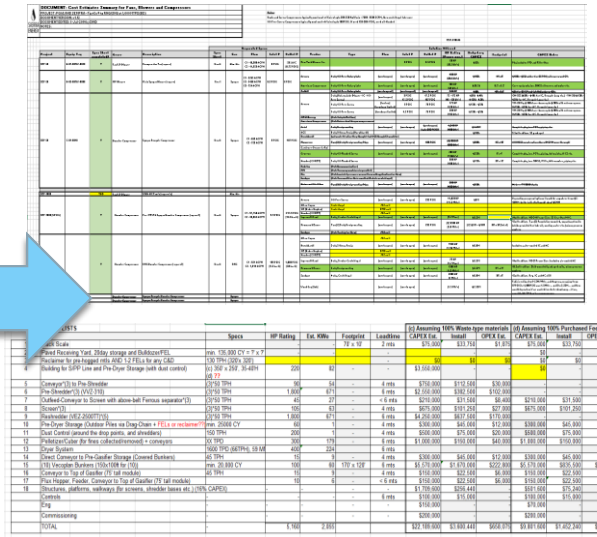












Study Results – RNG Quality

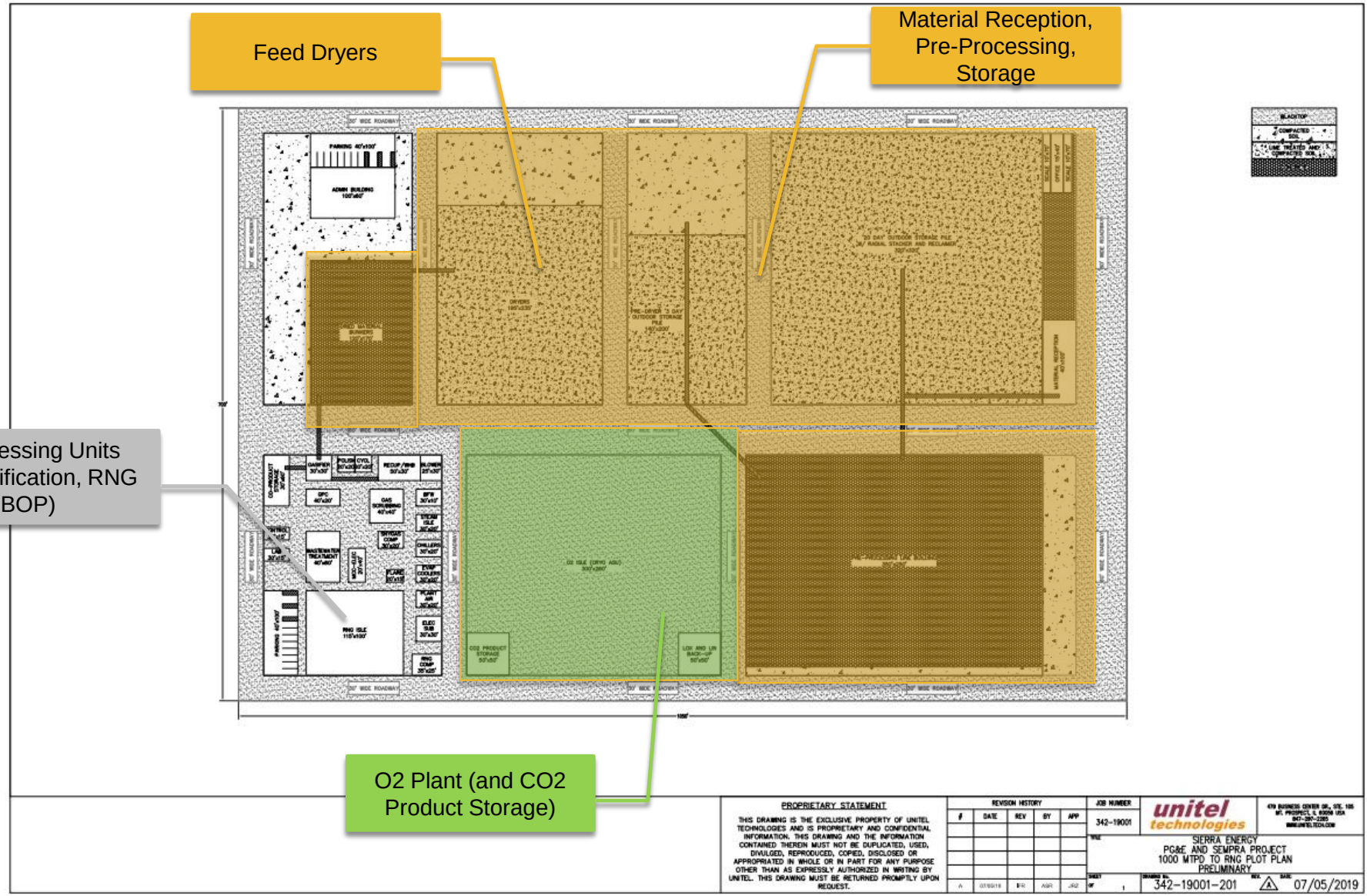
	SYNGAS	SNG
Temperature [C]	40	40
Pressure [bar_g]	15	9,6
Molar Flow [kgmole/h]	2997	640
Vol Flowrate [Nm3/h]	67184	14342
Mass Flow [kg/h]	59171	10564
Hydrogen	41,49%	0,04%
CO	41,56%	0,00%
CO2	16,05%	0,93%
H2O	0,53%	0,01%
Methane	0,00%	97,24%
Nitrogen	0,38%	1,78%
Ammonia	53 ppm	0
COS	9 ppm	0
H2S	273 ppm	0

Parameter	PG&E (Rule 21)	Sempra (Rule 30)	Wood Grp (VESTA) Product	Meet Spec?
Quality of Gas				
CO2	**<= 1.00 %vol.**	<= 3.00 %vol.	0.93 %vol.	Y
O2	**<= 0.10 %vol.**	<= 0.20 %vol.	0.00 %vol.	Y
Inerts - Total (CO2, N2, O2 etc.)	-	**<= 4.00 %vol.**	2.71 %vol.	Y
S - H2S	<= 4 ppmV	**<= 4 ppmV. And, zero H2S-treatment solvent or by-product**	0 ppmV	Y
S - Mercaptan	<= 8 ppmV	**<= 5 ppmV**	0 ppmV	Y
S - Total	<= 17 ppmV	**<= 12.6 ppmV**	0 ppmV	Y
H2O, P <= 800 PSIG	**<= 7lb(H2O)/1MMSCF @ 800PSIG**			
H2O, P > 800 PSIG	**Dewpoint <= 20°F**		TBC.	Y
Hydrocarbon Dewpoint, P <= 800 PSIG	**<= 45 °F @ 400 PSIG**			
Hydrocarbon Dewpoint, P > 800 PSIG	**<= 20 °F @ 400 PSIG**			
Liquids	**zero**			
Merchantability	**zero dust, sand dirt, gum, oils etc.**			
Temperature	**60 °F < T_injection <= 100 °F**	50 °F < T_injection <= 105 °F	90 °F	Y
Heating Valve - HHV	Consistent with Receipt Point	**970 <= HHV, BTU/scf(dry) <= 1150**	983.3 BTU/scf(dry)	Y
Interchangability	-	**1279 <= Wobbe <= 1385**		
Biomethane Max Allowable Constituents				
Carcinogenic	n/a for this study - wouldn't be accurately modeled			
Non-Carcinogenic	n/a for this study - wouldn't be accurately modeled			
Pipeline Integrity				
NH3	**0.001 %vol.**		0 ppmV	Y
H2	**0.10 %vol.**		0.04 % vol.	Y
Hg	**0.08 mg/m3**			
Siloxanes	**0.01 mg(Si)/m3**			

Note: 1 SCF (standard cubic foot) gas is measured at 1 atmosphere and 70°F.

Study Results – Plot Plan

Preliminary Site:
1050’ x 700’
= 735,000 SF
= 17 acres



Study Results – CAPEX (LP scenario)

Major Equipment / Isle	Modularized / Packaged Equip CAPEX
Waste Pre-Processing Isle	$38,740,000
FastOx Gasification (GPRC) Isle	$35,600,000
Gas Cleaning Isles	$5,115,000
RNG Isle	$35,850,000
Oxygen Production	$51,000,000
Utilities Isles	$11,765,000
	$178,070,000

Category	Cost
Total Modular Equipment and Isle Costs	$178,070,000
Additional Installation Costs	$60,000,000
Project Development Costs	$45,210,000
TICC (+/- 30%)	$283,300,000

Note: Installation and Project Development Costs are highly-specific on site selected.

Study Results – LCA

- UCD LCA and Report
- Assumed smaller, 50MTPD system (less efficient), assumed 90% uptime (at 1,000MTPD would be 95%) and MSW (significantly higher CI compared to biomass/wood waste).

Chair of Technical Thermodynamics | RWTH AACHEN UNIVERSITY

The present work was submitted to Chair of Technical Thermodynamics

Assessing the Environmental Impacts of the FastOx® Gasifier as a Waste Utilization Technology

Bachelor's Thesis

presented by
Ganter, Alissa
StudentID no. 355 918

Supervisor:
Professor Alissa Kendall, Ph.D.
Marvin Bachmann, M.Sc.

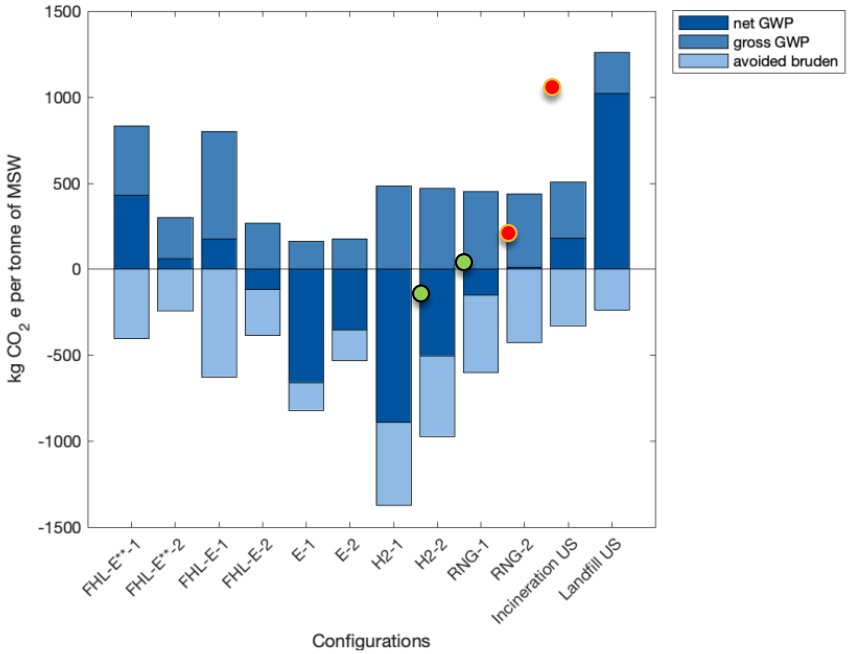


Figure 4.3.: Comparison of the FastOx® Configurations

Configurations	EER	Carbon Intensity	LCFS credit
FHL-E-1	3.4	51 $g_{CO_2\,eq.}/MJ$	0.18 $/kWh
FHL-E-2	3.4	-85 $g_{CO_2\,eq.}/MJ$	0.22 $/kWh
E-1	3.4	-42 $g_{CO_2\,eq.}/MJ$	0.24 $/kWh
E-2	3.4	-65 $g_{CO_2\,eq.}/MJ$	0.25 $/kWh
H_2-1	2.5	11 $g_{CO_2\,eq.}/MJ$	4.93 $/kg
H_2-2	2.5	14 $g_{CO_2\,eq.}/MJ$	4.86 $/kg
RNG-1	1	12 $g_{CO_2\,eq.}/MJ$	15.85 $/MMBTU
RNG-2	1	15 $g_{CO_2\,eq.}/MJ$	15.47 $/MMBTU

Table 3.5.: Settings of the LCFS credit price calculator and LCFS credit results

Study Results – Simple 10yr Breakeven Price

- HP more favorable over LP
- Syngas recycle (SR) more favorable over nat. gas (NG) procurement.
- Assumption: all CAPEX absorbed in Yr0, (no discounts or grants)

Config	TICC	RNG Produced	LCFS Credit	Feed Mtl. Tip Fee	10-Year Break-Even	
					Annual Profit	SNG Sale Price Req.
	[$MM]	[MMBTU/d]	[$/MMBTU]	[$/ ton]	[$MM/yr]	[$/MMBTU]
LP (<15 PSIG), NG	$283.3	12,870	$15.85	$30.00	$28.3	-$1.62
				$0.00	$28.3	$2.17
				-$30.00	$28.3	$7.51
			$0.00	$30.00	$28.3	$12.68
				$0.00	$28.3	$18.02
				-$30.00	$28.3	$23.37
LP (<15 PSIG), SR	$283.3	11,433	$15.47	$30.00	$28.3	-$5.98
				$0.00	$28.3	-$1.92
				-$30.00	$28.3	$2.14
			$0.00	$30.00	$28.3	$9.49
				$0.00	$28.3	$13.55
				-$30.00	$28.3	$17.61
HP (150 PSIG), NG	$277.1	13,071	$15.85	$30.00	$27.7	-$2.35
				$0.00	$27.7	$0.39
				-$30.00	$27.7	$6.42
			$0.00	$30.00	$27.7	$10.22
				$0.00	$27.7	$16.24
				-$30.00	$27.7	$22.27
HP (150 PSIG), SR	$277.1	11,548	$15.47	$30.00	$27.7	-$8.83
				$0.00	$27.7	-$4.81
				-$30.00	$27.7	-$0.79
			$0.00	$30.00	$27.7	$6.64
				$0.00	$27.7	$10.66
				-$30.00	$27.7	$14.68

Study Results – LCOF and Sensitivity Analysis

CEC - Levelized Cost of Fuel Calculator

CALCULATOR: LEVELIZED COST OF SNG PRODUCTION

Based upon the California Energy Commission's LCOF calculator, supplied by CEC's ARFVTP group

$$Levelized\ Cost\ of\ Fuel\ [\$/MMBTU] = \left(\frac{(Amortized\ CapEx + Net\ OpEx)\ [\$/y]}{Annual\ RNG\ Production\ in\ 1\ Year\ [MMBTU/y]}\right)$$

SCENARIO MODELED: 1,000MTPD biomass/wood waste converted in the 'High Pressure' FastOx Gasification system with Syngas Recycle. LCFS credits available. RFS credits not included.

CapEx also known as Total Capital Investment (TCI) Inputs:	
Equipment Cost (installed):	$277.10
Materials/Parts Cost (installed):	inc. in Equip. Line
Labor Cost:	inc. in Equip. Line
Engineering Cost:	inc. in Equip. Line
Design Cost:	inc. in Equip. Line
Permitting Cost:	inc. in Equip. Line
Land Prep Cost:	inc. in Equip. Line
Other Cost:	inc. in Equip. Line
CapEx / TCI Grand Total: [$MM]	$277.10

Assumptions for amortizing Annual CapEX	
Debt fraction (fraction of TCI):	1.00
Amount of Debt ($MM borrowed):	$277.10
Debt Interest [%/y]:	3.00%
Debt Term [years]:	15
Equity fraction (fraction of TCI):	0.00
Amount of equity: $ million investment	$0.00
Return on Investment/Equity [%/y]:	12.00%
Project Life [years]:	15

OpEx (Fixed (costs that occurs whether the plant is operating or not) and non-feedstock Variable Expenses (Costs directly related or proportional to amount of products output by plant)) Inputs:	
Labor Cost (Fixed):	$4.24
Maintenance Cost (Fixed):	$4.43
Insurance Cost (Fixed):	$0.15
Technology Licence Cost (Fixed):	$0.40
Other (Fixed) Cost:	$0.00
Chemical (Variable) Cost:	$3.63
Utilities (Variable) Cost*:	$13.34
Air/Water/Waste Treatment or Disposal Cost:	$0.00
Other (Variable) Cost:	$0.00
Annual Gross OpEx: [$MM/y]	$26.19

*Utilities costs: Electricity [$/kWhe] $0.120; Nat. Gas [$/MMBTU] $3.000

LCOF [$/MMBTU]:	-$8.927

	[$MM/y]
Annual CapEx (amortized):	$26.70
Annual Gross OpEx:	$26.19
Feedstock Cost and Co-Product Sales:	-$88.63

Feedstock Cost and Co-Product Sales [$MM/y]	
Feedstock #1 Cost (-ve is revenue):	-$16.10
Co-Product Sales: (Inert Stone and Alloyed Metals)	-$72.54
Feedstock Grand Total:	-$88.63

Total SNG Production	
[MMBTU/y]:	4,004,000

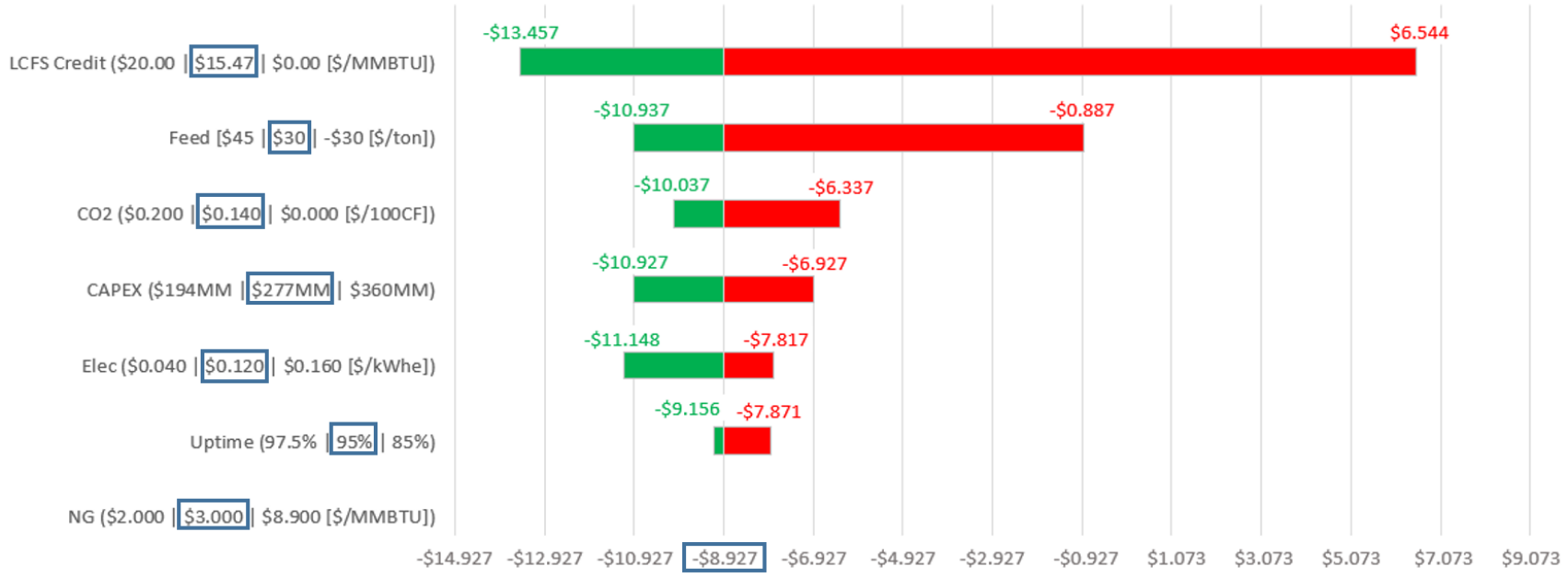
Other Revenue Inputs		Units
Tipping Fee / Cost (-ve):	$30.00	[$/ton]
	$16.10	[$MM / y]
Co-Product #1:	$20.00	[$/ton]
Inert Stone	$0.22	[$MM / y]
Co-Product #2:	$180.00	[$/ton]
Alloyed Metals	$0.00	[$MM / y]
Co-Product #3:	$0.140	[$/100CF]
CO2	$10.37	[$MM / y]
RFS Credits:	$0.00	[$/MMBTU]
	$0.00	[$MM / y]
LCFS Credits:	$15.47	[$/MMBTU]
	$61.95	[$MM / y]

Amortization Calculations	
Debt Payment for the debt term [$MM/y]	$26.70
Present Value (PV) of debt payment [$MM]	$277.10
Debt payment levelized over project life [$MM/y]	$26.70
Equity payment for life of project [$MM/y]	$0.00

Assumptions for RFS Credits	
Category and RIN Code	*$ per unit*
Cellulosic Biofuels - D3	
Biomass-derived Diesel - D4	
Advanced Biofuels - D5	
Renewable Fuel - D6	
Cellulosic Diesel - D7	

Comments/Notes:

- This LCOF calculation assumes the project receives wood waste with a corresponding tip fee $30.0/ton collected by the plant owners.
- The $15.47/MMBTU LCFS Credit was calculated by UC Davis, as part of an LCA study on the FastOx Technology. The carbon intensity (CI) of FastOx-produced RNG (assuming an MSW feedstock) was 15 gCO2E/MJ. Note, with biomass/wood waste, the CI would be even lower, and therefore return a greater LCFS credit for the plant owners and further revenue.
- The Waste-to-SNG system is assumed to have an annual uptime/availability of 95.0% which affects variable outputs and variable costs, while fixed costs remain identical (labor, maintenance etc. are assumed constant)
- "Equipment Cost (installed)" includes the cost of Site Development/Land Prep, Utilities Interconnects, all plant equipment/modules Procurement, Shipping, Install and Commissioning. It also included the "Engineering" and "Design" costs for both the modular system/equipment, and the overall site/plant.
- "Permitting Cost" includes all engineering and aquisition fees for environmental (CEQA, Air, Water, Waste) permits, local Use permits, and safety (Cal/OSHA etc.) permits, including inspections and 3rd-party compliance testing.
- The project is conservatively assumed to be 100% debt-financed. In reality, most projects would likely have some equity financing, some tax incentives, possibly even some grant funding too.



Presentation Conclusions

- **FastOx-based projects** for the conversion of waste wood exhibit **strong project economics that don't require Carbon Credits to be feasible**

- **Sierra Energy supports the Standard Renewable Gas Interconnection Tariff, as it will lower project development costs and interconnection costs (on both sides)**, lowering the cost of RNG, increasing project and technology adoption.

- **If the 'Maximum allowable H_2' in the injected RNG can be increased** (above the existing 0.10%vol. limit), this **would have additional positive impact on the RNG yield, and CAPEX and OPEX**, lowering RNG costs and further increasing project and technology adoption.